

The Incomparable Comparator

In our introduction to operational amplifiers, in the May issue, we explained that op-amps are seldom operated “open loop,” nearly always incorporating some degree of negative feedback. Without negative feedback, the op-amp has extremely high gain and is inherently unstable. In its “normal” application, the op-amp relies on negative feedback in order to act like a normal amplifier.

However, there is one application in which the op-amp is operated “wide open” with no negative feedback. This wide-open op-amp is known as the *comparator*.

With no negative feedback, a very small signal applied to either the inverting or non-inverting input causes the output voltage to swing to the extreme voltage possible, i.e., the power supply “rail” voltages. You may rightly compare this to a *limiter*, in this elementary mode; it basically converts any input signal to a square wave.

But remember that op-amps have differential inputs available. When operating without feedback, the output voltage will swing to one extreme or the other, depending on the *relative* voltages applied to the inputs. If the voltage applied to the inverting input is greater than that applied to the non-inverting input, the output voltage will go “hard negative.” If the voltage applied to the inverting input is *less* than that applied to the non-inverting input, the output voltage swings “hard positive.” This is a very useful property. Perhaps the most common application of this property is as a *threshold detector*.

How often do we need some device that will tell us when some specific value of voltage (or other parameter) is exceeded? There are countless applications for this fundamental function, of course, but let’s look at a very common one, a simple timer.

Tick-Tock

To begin with, how do we associate time with a voltage? The most obvious answer is the RC time constant, a capacitor charging (or discharging) through a

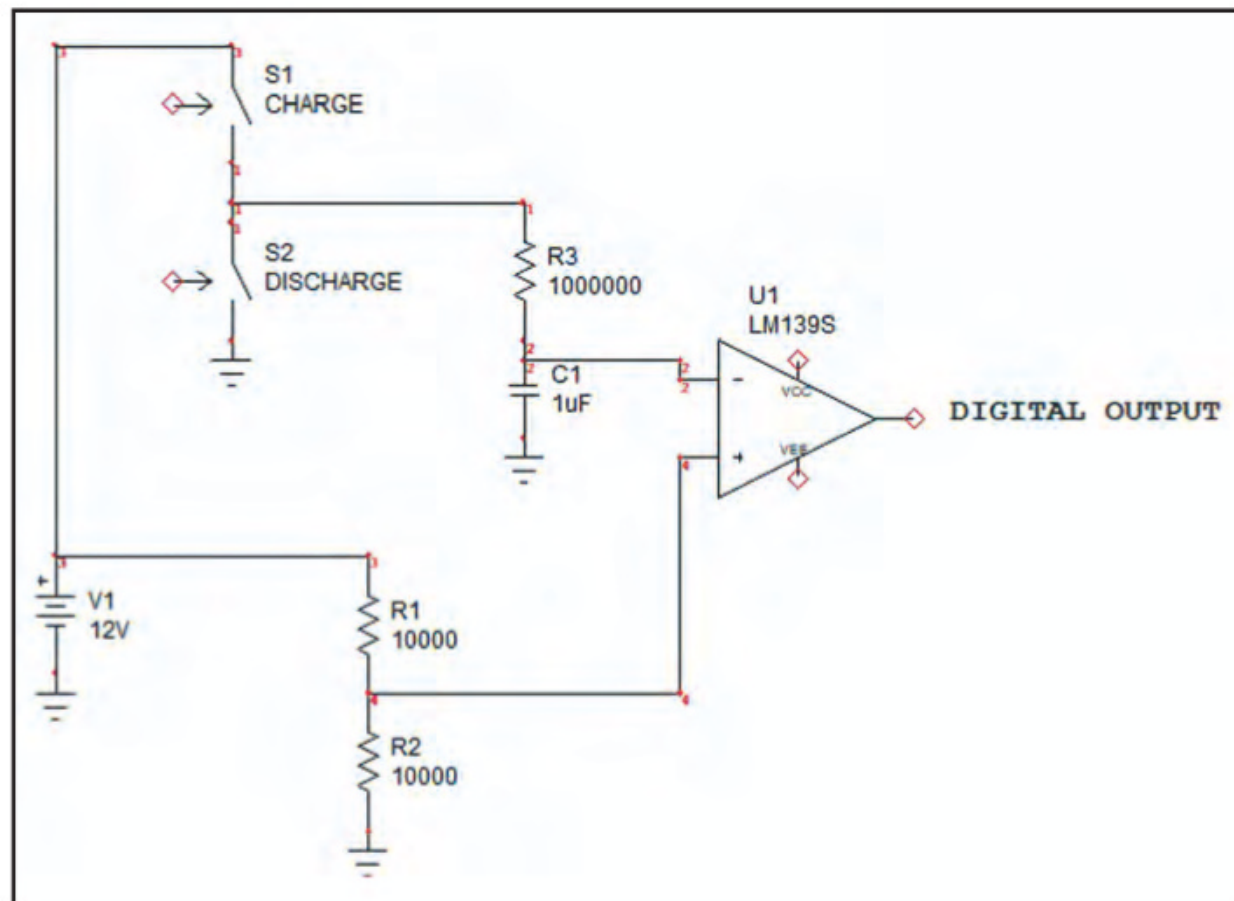


Figure 1. Basic comparator circuit, as described in the text.

resistor (Figure 1). While either the charge or discharge time constants can be used equally effectively, we will stick with the discharge time constant, both for consistency and for a slight increase in simplicity, which will become evident later on. We can use a 1-megohm resistor and a 1-microfarad capacitor to give us a 1-second time constant. Unfortunately (or fortunately, depending on your point of view), the RC discharge curve is not a straight line. It’s an exponential function. In this particular case, when one second elapses, the voltage across the capacitor will be 37% of the original voltage.

Each subsequent time constant will result in a voltage value of 37% of the previous time constant. As a rule-of-left-big-toe, a capacitor is deemed to be “fully” discharged after five time constants, at which point the voltage is less than 1% of the initial value. For the sake of this discussion, however, we’ll only talk about the first time constant.

From a practical standpoint, there’s nothing particularly sacred about the conventional time constant. We can create a self-defined time constant: For example, the time it takes for a resistor-capacitor combination to discharge to

HALF the initial voltage, instead of 37%. In fact, the *half-life* of radioactive decay uses this concept. So we can talk about the “half-life” of an RC circuit. The important thing to recognize is that it is a logarithmic function.

So, what sort of contraption can we use that will tell us that a capacitor’s voltage has dropped to half of its initial voltage? A comparator is a great choice for this job. So, let’s put together a half-voltage detector circuit, as shown in Figure 1. As always, we highly recommend that you actually assemble our example circuits.

Although some op-amps, such as the LM139 used in this circuit, are particularly suitable as comparators, the 741 will also work fine in this role ... usually. And, as always, we are assuming a bipolar power supply for the comparator itself, typically ± 15 volts. A separate 12-volt supply is used for the RC circuit.

In this circuit, R1 and R2 form a reference voltage divider, supplying 6 volts to the non-inverting input. If the voltage at the inverting input is any value *greater* than 6 volts, the output will be LOW (in this case, -15 volts). If the voltage at the inverting input is any

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value less than 6 volts, the output will go HIGH (+15 volts). We've supplied two single-throw single-pole switches for conveniently charging and discharging our capacitor. The “normal” time constant is determined by R3 and C1, which — in this case — should be one second. However, since we are using the *half-voltage* point to “trigger” the comparator, the time lapse will be a bit shorter.

Left as an Exercise

Didn't you just love high school textbooks (especially in math) that said, after some incomprehensible principle was (supposedly) explained, “The following is left as an exercise”? Well, since we're all consenting adults here, (whether still in high school or not), we'll leave as an exercise the determination of just *how long* it should take for the capacitor to discharge to *half* of its initial voltage. And, just for the record, it's not cheating to actually build the circuit and measure this. However, we should know how to calculate this sort of thing ahead of time. Although you can make almost *any* analog circuit function by “fiddling around” with component values, real engineering involves doing some calculations ahead of time.

So, your homework assignment for the next lesson is to figure out the “half-life” time of this circuit (show your work!). Send your answers to me at kl7aj@cq-amateur-radio.com, and we will share and compare your results with our other dedicated readers in the next installment.

Shifty

Although the simple circuit shown in *Figure 1* very effectively gives us a *digital* (YES or NO) output, depending on the state of capacitor voltage, it isn't necessarily the most convenient form. While we can certainly use +15 and -15 volts as digital logic values, it might be a bit of a challenge to interface it with “normal” digital circuitry, such as standard TTL logic, which uses 0 and 5 volts for the zeroes and ones. Circuits designed to convert one “style” of digital logic to another are known as *level-shifting* circuits, and can be extremely simple or very elaborate, depending on the application. And while level shifting is most commonly used in the *digital* domain, it is not limited to digital circuits. We will explore analog level shifting in detail in later columns.

Border Crossing

I trust you've all forgiven me for briefly going out of bounds and wandering into *digital* territory. If it's any consolation, N2IRZ, likewise, has shamelessly waltzed into *my* territory from his Digital Connection domain. (Excellent piece on oscilloscopes, by the way, Don!) This just brings up an important point: We live in a very *consistent* universe, held together by a very cohe-

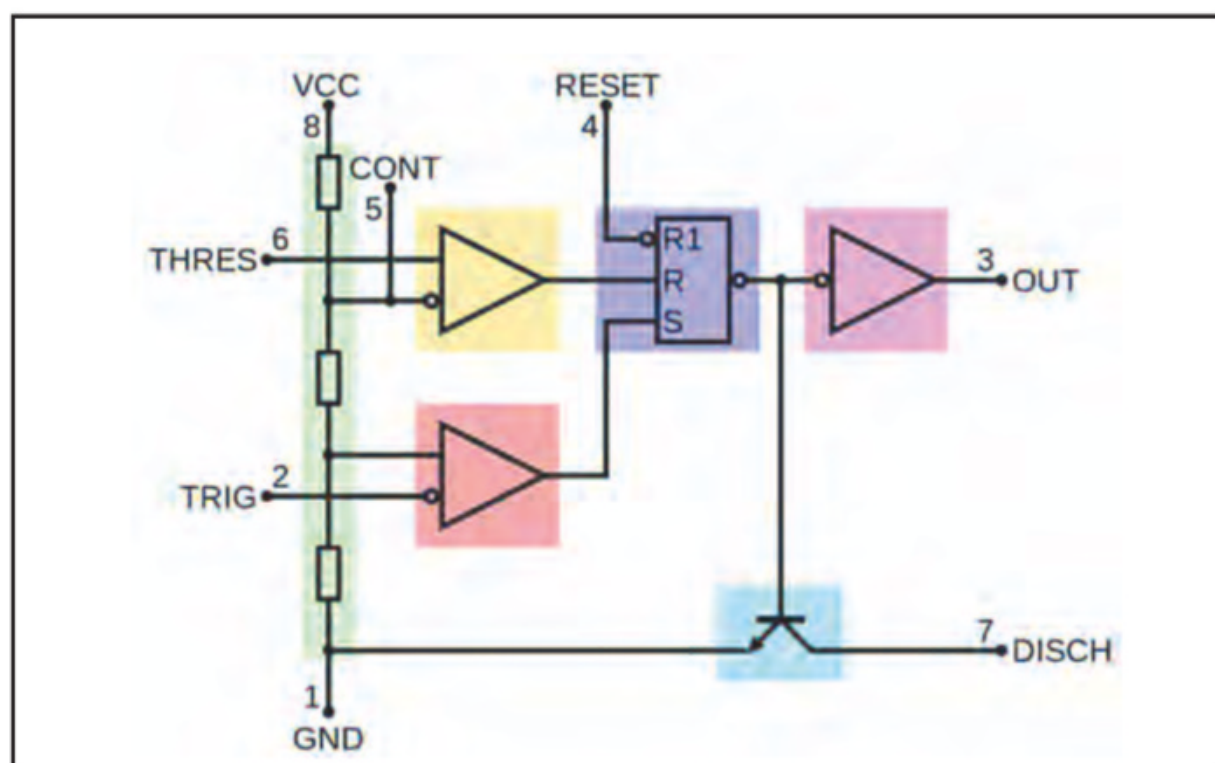


Figure 2. Block diagram of the 555 timer IC.

sive system of law and order. As presumably scientifically-minded hams, we need to be able to move effortlessly from one domain to another, as there are tremendous things to be learned from both analog and digital methods. And there are countless circuits and pieces of equipment that use both. Which brings us to...

The Venerable 555 Timer Chip

Nobody is really sure if the 555 timer chip is an analog or a digital device. It has features of both. However, as we alluded above, there's no need to confine it to either. According to Wikipedia, the 555 is the most popular IC ever created, and there's probably no reason to dispute this. I've used piles of them myself in my ham radio "career."

Figure 2 shows the block diagram of a 555. The full schematic is readily available as well, but we don't need to dive into that, at least not now. As you can see, the 555 contains a couple of comparators and a few other components which allow the device to work as a "one-shot" timer (similar to the circuit we constructed above), as an *astable multivibrator* (square wave oscillator), or a *pulse generator*. The "core" of the 555 is the upper left comparator, which functions essentially in the same manner as our circuit in Figure 1.

Back in the day (when you get to my age, *everything* was "back in the day"), the 555 was an exciting new product, and there were numerous 555 "cook-books" published to help the electronics student explore this chip's unique properties. I still have a nice collection of these that I loan out to my electronics students. One of my favorites is Forrest Mims' *Timer, Op Amp, and Optoelectronic Circuits and Projects*, which is still in print and available through W5YI/Master Publishing.

Speaking of optoelectronic circuits, the *opto-isolator*, which is one such device, is often used for *level shifting* as described earlier. It also has a lot of other uses, which we will explore later in this series. Opto-isolators can work in either a digital or analog mode, the latter of which is greatly underutilized in ham radio applications.

Well, it looks like it's about time to wrap up this installation. Next up, we'll begin putting together a *lock-in* amplifier, which will incorporate a lot of the principles we've covered so far.

Until then, keep the soldering iron hot, and the coffee perkin'.

— 73 es 88, Eric




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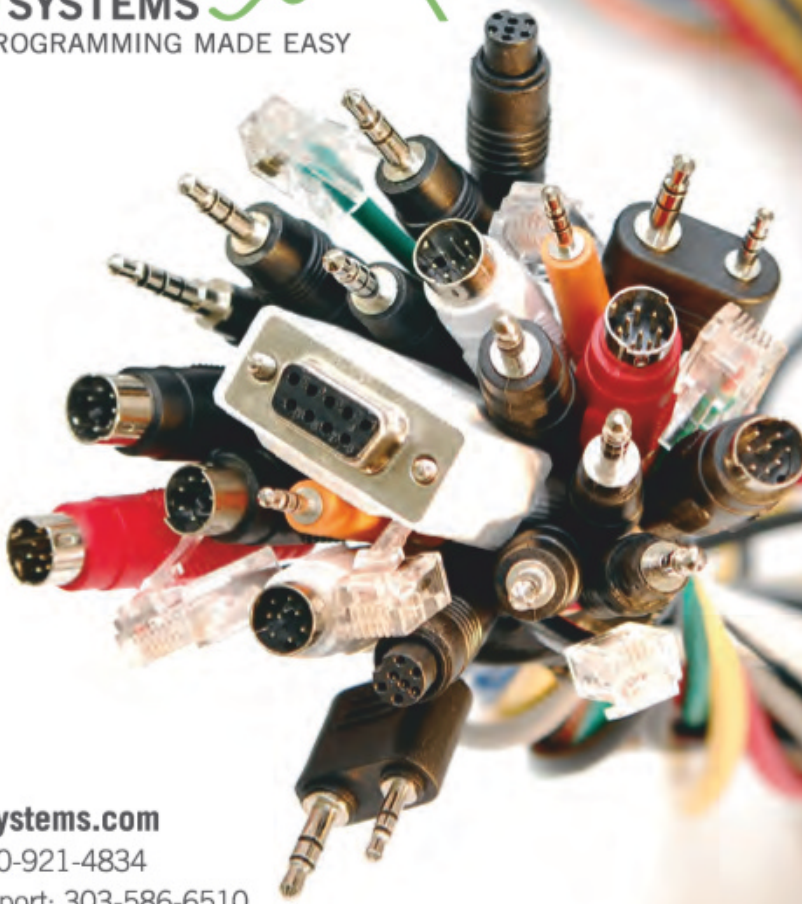
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